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THE ROLE OF GRONDWATER IN HUMAN SOCIETY

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In this presentation I want to show that groundwater involves more than a supply for a farm or cottage well but is an important factor in many geological phenomena as well as being a major component of stream flow and storm runoff. It has been, and is, a major factor in human societies. We have many examples of grave social problems that have their roots in poor planning or poor understanding or poor decisions in groundwater matters.

First, I want to refer to several technical matters that will remind you of the importance of groundwater in some phenomena that do not impact on our daily lives.

After many years of mainly qualitative or descriptive analyses of regional groundwater flow, Hubbert. in 1940, showed that this problem was amenable to analysis by potential- field methods used by physicists and mathematicians. His concepts were not well received at first by the people working in groundwater, probably because his assumptions or generalizations did not match those of classical hydrogeology. Twenty years later, Joe Toth, Alan Freeze and Paul Witherspoon applied computer analysis to field studies to demonstrate the validity of Hubbert's gravity flow system concept. Freeze went on to incorporate all subsurface flow into an analysis of the runoff cycle and and Toth has found very interesting relations between regional groundwater flow and oil pools. Reference to groundwater flow systems has become a trademark of field studies by Canadian hydrogeologists.

As long ago as 1960 Hubbert and Rubey published a pair of papers on the role of groundwater in overthrust faulting. They concluded that the only mechanism that could account for these great displacements (dozens of kilometres) by mountain-sized blocks of rock, was gravitational sliding on planes of excess pore- water pressure. They went on to show this situation could have existed during the time the faulting occurred.

In 1966, Evans described the "Denver Earthquakes" as caused by injection of liquid wastes in Precambrian rocks at a depth of about 3000m. Now Bredehoeft and his colleagues at the U.S. Geological Survey in Menlo Park, California, can cause earthquakes in Wyoming by sending commands to start deep- well injection.

These examples may seem very far from our normal concerns so I want to turn to groundwater in the sense that we usually deal with it- in the runoff cycle or in wells.

For his M.Sc. research at Waterloo, Mike Sklash used environmental isotopes (oxygen-18 and deuterium) to show that in small streams, storm sunoff is comprised mainly of groundwater. We all knew that base- flow was entirely groundwater- in southern Ontario it is about 40% of total stream discharge- but we did not expect to find so much of it in storm runoff. For his Ph. D. thesis Sklash showed this to be the rule in all basins he studied

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in Canada, and he proposed a mechanism to account for it. The idea is hard to accept but the results are hard to refute. One wonders why it has never been considered in routine engineering hydrology work. I offer three possibilities: 1) engineering hydrologists don't know about the work or don't believe the results; 2) it is not important in runoff modeling or analysis; or 3) it hasn't appeared in standard texts used in engineering schools.

Both flood water and storm flow have been important in human society since the dawn of civilization. I'd like to convince you by conjectures, that groundwater conditions of these earliest irrigation operations eventually led to the downfall of the society. We might think of it as the first social disaster caused by neglecting groundwater in operations and planning.

The favoured places for irrigation using floodwaters were and are, the flat lowlands of rivers and lakes plains, where the alluvial surface is flat and gently sloping.The soils are rich, and water is easily delivered to the fields. The agricultural society that first developed along the Tigris and Euphrates rivers thrived, in part we know, because of such favourable conditions. But the society eventually failed and students of ancient history commonly include water problems as one of the causes. In no case I know of do the historians consider the fact that the groundwater flow system may have been an important contributor to deteriorating conditions in the cultivated fields. The link is pretty obvious if we think about it. Surely, the irrigated fields were in a zone of groundwater discharge. We can assume this with some confidence merely from descriptions of the terrane- low-lying land adjacent to rivers. Normal evapotranspiration of the water by the crops would cause slow accumulation of salt and salinization would eventually become a serious problem. The common practise of flushing out the salt by using excessive application of irrigation water would not work because, being in a discharge zone, the upward groundwater gradient would would prevent downward drainage. Instead of flushing, there would be water- logging. Similar circumstances are noted in many major irrigation schemes of the past and present. According to Barney "worldwide an estimated 125,000 hectares of irrigated land are lost from production each year due to waterlogging, salinization, and alkalization."

Now I want to turn to the aspects of groundwater that we know best..water supply. Springs and streams with good base flow were and are, the favourite sites for human settlement. We note that if the supply is small, problems are few. People adapt their needs to what is available. In an extreme case, a small tropical island of carbonate sand is home to several families. Before setting foot on the island we can assume that a lense of fresh water occurs in the porous sand, floating on saline ocean water, with a recharge- discharge regime like that proposed by Hubbert. The inhabitants can get water from shallow pits, and as long as they use only fresh water that is about to be discharged into the sea, they have a secure supply. A similar condition occurs on a larger, neighbouring island. Here, discharge occurs in a contact spring, and the inhabitants have a secure supply. The City of Kupang, Indonesia, a few kilometres away, was established and grew around similar springs. Surface water is almost non- existent, because of the highly permeable limestone. Now, less than 50% of the inhabitants are served by the water system, and those get service less than 50% of the time. Improvement of the system is planned, so that some 80% of the people will have a continual supply of water. The question then is, how much groundwater is available? Surface water sources are far away and even then, reservoir sites are either on the cavernous limestone or a clay formation that is unstable in the extreme. The clay slopes seem almost in motion and are dangerous in the rainy season.

A similar hydrogeological situation is encountered on western part of the island of Java. The springs at Bogor provided a bountiful supply of water to the local people and the port of Jakarta. Now Jakarta has a population of seven million. Less than one-third of the people have water service and many depend on the half-million or more shallow wells. The drawdown from over pumping has reversed the natural hydraulic gradients of this discharge zone, allowing sea- water intrusion and downward flow of contaminants from the surface. As in Kupang, alternative sources for municipal supply are costly and difficult. These centres have simply become too big for the water supply that served them so well in earlier times.

It is really a pretty common thing to see a city that has outgrown its original water source and needs a new one. In most of our experience, this means extensive studies and major capital investment. In Canada, in general, we can buy our way out of this sort of difficulty. In Kupang and Jakarta, it is not easy to see a solution, at any reasonable cost. What is obvious is that the groundwater resource has a high real value and that production must be "maximized" as we say, meaning we must get the most water out of the system that is possible for the longest time and with the lowest possible negative consequences.

We accept the problems and costs of water supplies of cities as one of the consequences of the social dynamism that stimulates their growth. No one is to blame and the answer, for we Westerners at least, is to get more water, whatever the cost. In Canada, at least, we can solve almost any water supply problem by spending money, and this seems to find general favour.

We might like think that in use of water for personal business and profit we would behave more responsibly: we would nuture our resources and think ahead and consider the long-term consequences, with respect both to our own good and that of the common good. The record indicates otherwise.

Consider the man in Nigeria, working his "shadoof" to raise water from the pothole in the dry river bed. At this place no rain has ever been recorded during the three or four driest months. His market garden provides him with a good living. It's not a great step, technically, to dig wells in the alluvium nearby for domestic supply, and then to step out farther and dig wells up to 60 metres deep to reach the water table. Over this region and elsewhere in the "Sahel", groundwater occurs in great abundance in good aquifers. It is not over-exploited, perhaps in part because of local farming tradition and methods, but perhaps also because there is no obvious market for their crops and so no capital is invested in wells and pumps that could quickly deplete the

groundwater reservoir. This resource will be available for the use of the next generation at least.

Over- exploitation for agriculture without concern for the needs of future generations is common where the favourable combination of soils, terrain, climate and water are found along with economic opportunity. In the High Plains of the south - central U.S.A. the enormous reserve of groundwater in the Ogallala formation is exploited by some 170 thousand wells for irrigation of crops, that a few years ago were surplus to demands and so supported by Federal subsidies. Regional economy depends on this industry which must be short- lived because of the rapid depletion of the groundwater reserve. The current generation of land-owners are making their living through this depletion. Suggestions for conservation have not been heeded; in fact the owners now get a Tax Depletion Allowance that recognizes their land is depreciating in value as they mine the groundwater.

In the Comarca Lagunera in northern Mexico an extensive irrigated area and the commercial centre of Torreon, with a population of a million or so , depend mainly on groundwater. Here to as in 60 other groundwater basins in Mexico, depletion is a serious matter. The water table has fallen from near surface to 100m and more, and the decline is several metres per year. A regional economy and society is dependent on the resource and in this case there simply is no other resonable alternative, but there is some economic control on over- exploitation - the cost of deepening wells and lifting the water 100 m. Not much scientific study has been done on groundwater in the Lagunera, although it is certain that here too, the use of the groundwater resource must be maximized. Research or engineering studies are not encouraged by authorities. Perhaps their reluctance is related to fact that some 60% of the adult population suffers symptoms of chronic arsenic poisoning. The groundwater throughout most of the basin exceeds the recommended limit of 0.05 mg/l of arsenic and the political implications are not looked on with much joy by those responsible.

Surface- water developments for export to distant centres is common and now groundwater is viewed for the same purpose. In Libya, an enormous reserve of groundwater was discovered during petroleum exploration in the Sahara Desert. Now, a pipeline some two metres in diameter carries water from the water- well- fields hundreds of kilometers north to Tripoli for irrigation and municipal supply. The reservoir of groundwater is great, but it is also non-renewable. The consequences are irreversible.

A similar plan was made by Mexicans for supplying water to the growing cities of Ensenada and and neighbouring region. Flow in the Colorado River is guaranteed by international treaty but the quality is bad because the water has become salty through evaporation in irrigation in the U.S.A. The aquifers underlying the Sonoran Desert are capable of supplying the Ensenada pipeline but here too, the resource is non-renewable. But the Mexicans have run into another complication. The aquifer is truly regional and extends across the international frontier. Americans have objected to the plan because the drawdown cone will reach into the U.S. one defense is to establish a line of wells on the north side of the border to create a drawdown cone and gradient that will keep their groundwater from flowing south to the Mexican wells. So here we have an international confrontation over groundwater and the spectacle of batteries of wells, not artillery, lined up and ready for a pumping war.

For me, the ultimate in groundwater problems is found in Mexico City, where 20 million people live in a closed basin at 2250 m elevation, using 65m3/s of water of which more than 40m3/s is from groundwater within the basin. The consequences are serious and include land- subsidence, groundwater depletion and contamination, and serious drainage problems. Water demand is increasing at about the same rate as the population, which is expected to be about 30 million by the year 2000. Surface water supplies are almost out- of- the- question. Streams within the basin are too small to be important sources. Streams beyond the basin divides are also too small and where they join with tributaries downstream and have larger flows, they are far below and far away from the City. The cost of bringing in surface water to the City is more the ten times the cost of producing groundwater from wells: this water has a great marginal value. Groundwater is clearly an important issue in affairs of people in many different times, places, and circumstances. In most cases we can say frankly that groundwater -related problems are not dealt with in a strictly rational manner. In my view, the Technology Transfer Conferences of MOE are good evidence that in Ontario at least, there is a will to do better.

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